23 Rec'd PCT/PTO 27 NOV 1998

FORM PTO-1390 (Modified) (REV 10-95) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER
9847-0004-6X PCT

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR
09/147320

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/SE97/00903	**27 May 1997**	**29 May 1996 earliest**

TITLE OF INVENTION
INSULATED CONDUCTOR FOR HIGH-VOLTAGE WINDINGS

APPLICANT(S) FOR DO/EO/US
Mats LEIJON, et al

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☒ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ A copy of the International Search Report (PCT/ISA/210).
8. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☒ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 13 to 18 below concern document(s) or information included:

13. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
    A **SECOND** or **SUBSEQUENT** preliminary amendment.
16. ☐ A substitute specification.
17. ☐ A change of power of attorney and/or address letter.
18. ☐ Certificate of Mailing by Express Mail
19. ☒ Other items or information:

Notice of Priority
Clean Copy of Specification (as amended by Preliminary Amendment)
PCT/IB/304
Request For Consideration of Documents Cited in International Search Report

PCTUS1/REV03

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR	INTERNATIONAL APPLICATION NO. PCT/SE97/00903	ATTORNEY'S DOCKET NUMBER 9847-0004-6X PCT

20. The following fees are submitted:.

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

	Fee	CALCULATIONS	PTO USE ONLY
☐ Search Report has been prepared by the EPO or JPO	**$930.00**		
☐ International preliminary examination fee paid to USPTO (37 CFR 1.482)	$670.00		
☐ No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2))	$760.00		
☒ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2) paid to USPTO	$970.00		
☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4)	$96.00		
ENTER APPROPRIATE BASIC FEE AMOUNT =		**$970.00**	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☒ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).		**$130.00**	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	20 - 20 =	0	x $18.00	**$0.00**	
Independent claims	4 - 3 =	1	x $78.00	**$78.00**	
Multiple Dependent Claims **(check if applicable)**.			☐	**$0.00**	
	TOTAL OF ABOVE CALCULATIONS		=	**$1,178.00**	
Reduction of 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28) **(check if applicable).**			☐	**$0.00**	
	SUBTOTAL		=	**$1,178.00**	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)).			+	**$0.00**	
	TOTAL NATIONAL FEE		=	**$1,178.00**	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).**			☐	**$0.00**	
	TOTAL FEES ENCLOSED		=	**$1,178.00**	
				Amount to be: refunded	$
				charged	$

☒ A check in the amount of **$1,178.00** to cover the above fees is enclosed.

☐ Please charge my Deposit Account No. in the amount of to cover the above fees. A duplicate copy of this sheet is enclosed.

☒ The Commissioner is hereby authorized to charge any fees which may be required, or credit any overpayment to Deposit Account No. **15-0030** A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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Nov. 25, 1998
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BRADLEY D. LYTLE
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9847-0004-6X PCT

IN THE UNITED STATES PATENT & TRADEMARK OFFICE

IN RE APPLICATION OF: :

PETER CARTENSEN ET AL : ATTN: APPLICATION DIVISION

SERIAL NO: NEW PCT APPLICATION :
(BASED ON PCT/SE97/00903)

FILED: HEREWITH :

FOR: INSULATED CONDUCTOR FOR
HIGH-VOLTAGE WINDINGS

PRELIMINARY AMENDMENT

ASSISTANT COMMISSIONER OF PATENTS & TRADEMARKS
WASHINGTON, D.C. 20231

SIR:

Prior to examination, please amend the above-identified application as follows:

IN THE SPECIFICATION

Page 1, before the title, insert

--TITLE OF THE INVENTION--;

after the title, insert

--BACKGROUND OF THE INVENTION

Field of the Invention:--;

line 5, delete "."; delete paragraph break;

line 7, replace ". A" with --and in a--; and delete "of the present invention relates";

line 8, replace "comprising an" with --having the--; after conductor insert --.--; and delete "of the type described";

line 9, delete "above."

line 11, change "The" to --More particularly, the--;

line 12, after "machines" (third occurrence) insert --such--;

line 16, replace "consist of" with --use the--; and after "described" insert --above--;

lines 16 and 17, delete "in the introduction";

line 17, replace ". "High voltages" here refer" to --, referring--;

line 21, replace "BACKGROUND ART" with

--DISCUSSION OF THE BACKGROUND--;

line 27, change "technique" to --techniques--;

line 28, after "circuit" insert --discussed--;

line 37, insert quote marks before and after "coil side".

Page 2, line 1, insert quote marks before and after "end winding end";

line 5, change "fibre" to --fiber--;

line 8, after "earth" insert --(i.e., ground potential)--;

line 9, change "fibre" with --fiber--;

line 21, after "for" insert --hosting--; after "coolant" insert --therein--;

line 24, after "is made" insert --so as--;

line 36, change "ac" to --AC--.

Page 3, line 6, after "span" insert --it--;

line 36, delete "the advantage".

Page 4, line 9, after "to" insert --identify--;

line 11, after "US" insert --Patent No.--;

line 12, after "4,429,244" insert --entitled--; after "Generator" insert --,--;

line 23, change ". As" to --, as--.

Page 5, line 1, change "means" to --way--;

lines 29 and 30 replace "is judged by" with --results of--;

line 30, after "investigation" insert --,--; and delete "to";

line 32, after "that" and "time" insert --,--;

line 37, before "monolith" insert --"--; and same line change "armature," to --armature",--.

Page 6, line 2, change "beings" to --being--;

line 6, change "technique" to --techniques--;

line 9, change "Obvious" to --Clear--;

line 28, change "ac" to --AC--.

Page 7, change "comprises" to --has--;

line 16, delete "is";

line 25, after "conductive" insert --(actually semiconductive)--.

Page 8, line 17, change "beings" to --being--;

line 24, replace "this" with --the inner conductive layer of the insulator--;

line 26, replace "are" with --include--;

line 34, replace "comprises" with --includes--.

Page 9, line 7, after "layer" insert --(which may include a semiconductive layer)--;

line 10, change both occurrences of "poly ethylene)" to --polyethylene),--; same line, after "(polypropylene)" insert --,--;

line 11, change "(poly butulene)" to --(polybutylene),--; same line change (poly methylpentene)" to --(polymethylpentene)--;

line 12, change "poly ethylene" to --polyethylene--;

line 16, delete "thus";

line 30, change "means" to --way--.

Page 10, line 10, after "conductive" insert --layer--;

line 12, change "between" to --therebetween--;

line 15, change "comprises" to --includes--;

line 19, "consist of" to --have--;

line 28, after "as" delete the rest of the line and insert therein --described herein--;

line 29, delete in its entirety;

line 30, delete "7"; and replace "comprises" with --includes--;

line 33, replace "earthed" with --connected to ground potential--.

Page 11, line 4, change "means" to --way--;

line 13, move "BRIEF DESCRIPTION OF THE DRAWINGS" before the previous paragraph;

line 14, change "through" to --of--;

line 20, change "shows a diagram" to --is a graph--;

line 21, change "earthing" to --grounded--;

line 23, after "OF" insert --PREFERRED--; and delete "OF THE PRESENT";

line 24, delete in its entirety;

line 25, before "Figure 1" insert --Referring now to the drawings, wherein like reference numerals designate identical or corresponding parts throughout the several views, and more particularly to Figure 1,--;

line 26, change "comprises" to --includes--;

line 27, change "consist of" to --have--;

line 34, after "between the" insert --second--.

Page 12, line 6, change "-" to --through--;

line 8, change "earthing" to --grounding--;

line 16, after "unit" delete --,--;

line 18, after "18" insert --,--;

line 27, change "earthed" to --grounded--;

line 29, after "conductive" insert --material--.

IN THE CLAIMS

Please cancel without prejudice or disclaimer Claims 1-18.

Please add new Claims 19-38 as follows:

--19. An insulated conductor for a high-voltage winding in an electric machine, comprising:

one or more strands;

an inner conductive layer that surrounds said one or more strands;

an insulating layer that surrounds said inner conductive layer; and

an outer conductive layer that surrounds said insulating layer, wherein:

a resistivity of the outer conductive layer being in an inclusive range of 10 through 500 ohm*cm.

20. An insulated conductor as claimed in claim 19, wherein:

the outer conductive layer is grounded at at least two different points.

21 An insulated conductor as claimed in claim 20, wherein:

said outer conductive layer having a resistivity being lower than that of the insulating layer but higher than that of a material that comprises said one or more strands.

22. An insulated conductor as claimed in claim 19, wherein:

the resistivity of the outer conductive layer being in an inclusive range of 50 through 100 ohm*cm.

23. An insulated conductor as claimed in claim 19, wherein:

a resistance per axial length unit of the outer conductive layer being in an inclusive range of 5 through 50000 ohm/m.

24. An insulated conductor as claimed in claim 19, wherein:

a resistance per axial length unit of the outer conductive layer being in an inclusive range of 500 through 25000 ohm/m.

25. An insulated conductor as claimed in claim 19, wherein:

a resistance per axial length unit of the outer conductive layer being in an inclusive range of 2500 through 5000 ohm/m.

26. An insulated conductor as claimed in claim 19, wherein:

said outer conductor including a base polymer and a carbon black,

a resistivity of the outer conductive layer being set by

a type of the base polymer,

a type of the carbon black, and

a proportion of the carbon black relative to an entire formulation of said outer conductive layer.

27. An insulated conductor as claimed in claim 26, wherein:

the base polymer comprises an ethylene butyl acrylate copolymer of EP-rubber.

28. An insulated conductor as claimed in claim 25, wherein:

the outer conductive layer being cross-linked by peroxide.

29. An insulated conductor as claimed in claim 26, wherein:

the outer conductive layer being cross-linked by peroxide.

30. An insulated conductor as claimed in claim 19, wherein:

an adhesion between the insulating layer and the outer conductive layer being of a same order of magnitude as an intrinsic strength of a material that forms said insulating layer.

31. An insulated conductor as claimed in claim 19, wherein:

the inner conductive layer, the insulating layer and the outer conductive layer are extruded on the one or more strands.

32. An insulated conductor as claimed in claim 30, wherein:

the inner conductive layer, the insulating layer and the outer conductive layer are applied through extrusion through a multilayer head.

33. An insulated conductor as claimed in claim 19, wherein:

the insulating layer being a crosslinked polyethylene, XLPE.

34. An insulated conductor as claimed in claim 19, wherein:

the insulating layer being at least one of ethylene propylene rubber and silicone rubber.

35. An insulated conductor as claimed in claim 19 wherein:

the insulating layer being a thermoplastic material from a set of LDPE, HDPE, PP, PB, and PMP.

36. An electric machine comprising:

an insulated conductor for a high-voltage winding, having

one or more strands,

an inner conductive layer that surrounds said one or more strands,

an insulating layer that surrounds said inner conductive layer, and

an outer conductive layer that surrounds said insulating layer, wherein:

a resistivity of the outer conductive layer being in an inclusive range of 10 through 500 ohm*cm. .

37. A rotating electrical machine comprising:

an insulated conductor for a high-voltage winding, having

one or more strands,

an inner conductive layer that surrounds said one or more strands,

an insulating layer that surrounds said inner conductive layer, and

an outer conductive layer that surrounds said insulating layer, wherein:

a resistivity of the outer conductive layer being in an inclusive range of 10 through 500 ohm*cm.

38. An insulated conductor for a high-voltage winding in an electric machine, comprising:

means for conducting an electrical current in said high-voltage winding,

means for electrically insulating said means for conducting, said means for electrically insulating having,

means for creating a first equipotential surface around said means for conducting,

means for creating a second equipotential surface around said means for creating the first equipotential surface, and

means for separating said first equipotential surface from said second equipotential surface; and

means for setting a resistivity of the means for creating a second equipotential surface to avoid glow discharge and limit eddy current losses.--

IN THE ABSTRACT OF THE DISCLOSURE

After page 17, please add the following abstract:

--An insulated conductor for a high-voltage winding in an electric machine, and rotating electric machine that use the insulated conductor. The insulated conductor is suitable for use in a high-voltage winding application for devices such as the electric machine and a rotating electric machine. A feature of the insulated conductor is that the conductor includes at least one strand, and an inner conductive layer that surrounds the at least one strand. An insulating layer surrounds the inner conductive layer, and an outer conductive layer surrounds the insulating layer. When arranged in this manner, and when the outer conductive layer is suitably configured to provide an equipotential surface, the insulated conductor provides relatively high resistance to breakdown when operating at high voltages.--

REMARKS

Favorable consideration of this application as presently amended and in light of the following discussion is respectfully requested.

Claims 19-38 are pending, Claims 1-18 having been canceled without prejudice or disclaimer and Claims 19-38 having been added by way of the present amendment. New Claims 19-38 find support in original Claims 1-18 and in the specification as originally filed, and consequently no new matter is added.

While numerous amendments have been made to the specification, consistent with accepted U.S. patent application drafting format, each amendment is believed to be made as a matter of form. However, to the extent any amendment is substantively inconsistent with the originally filed specification, the language included in the originally filed specification should be construed as containing the controlling language. Due to the large number of changes, and for the examiner's convenience, a "clean copy" of the specification is filed herewith that includes all of the amendments made by way of the present preliminary amendment.

Consequently, in view of the present amendment, an action on the merits is earnestly solicited.

Respectfully submitted,

OBLON, SPIVAK, MCCLELLAND,
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9847-0004-6X PCT

TITLE OF THE INVENTION

INSULATED CONDUCTOR FOR HIGH-VOLTAGE WINDINGS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates in a first aspect to an insulated conductor for high voltage windings in electric machines and in a second aspect to a rotating electric machine or static electrical machine having the insulated conductor.

More particularly, the invention is applicable in rotating electric machines such as synchronous machines or asynchronous machines as well as static electrical machines such as power transformers and power reactors. The invention is also applicable in other electric machines such as dual-fed machines, and applications in asynchronous static current cascades, outer pole machines and synchronous flow machines, provided their windings use the insulated electric conductors of the type described above, and preferably at high voltages, referring to electric voltages exceeding 10 kV. A typical working range for an insulated conductor for high-voltage windings according to the invention may be 1-800 kV.

Discussion of the Background:

In order to be able to explain and describe the machine, a brief description of a rotating electric machine will first be given exemplified on the basis of a synchronous machine. The first part of the description substantially relates to the magnetic circuit of such a machine and how it is constructed according to classical techniques. Since the magnetic circuit referred to in most cases is located in the stator, the magnetic circuit discussed below will normally be described as a stator with a laminated core, the winding of which will be

referred to as a stator winding, and the slots in the laminated core for the winding will be referred to as stator slots or simply slots.

The stator winding is located in slots in the sheet iron core, the slots normally having a rectangular or trapezoidal cross section as that of a rectangle or a trapezoid. Each winding phase comprises a number of series-connected coil groups connected in series and each coil group comprises a number of series-connected coils connected in series. The different parts of the coil are designated "coil side" for the part which is placed in the stator and "end winding end" for that part which is located outside the stator. A coil comprises one or more conductors brought together in height and/or width.

Between each conductor there is a thin insulation, for example epoxy/glass fiber.

The coil is insulated from the slot with a coil insulation, that is, an insulation intended to withstand the rated voltage of the machine to earth (i.e., ground potential). As insulating material, various plastic, varnish and glass fiber materials may be used. Usually, so-called mica tape is used, which is a mixture of mica and hard plastic, especially produced to provide resistance to partial discharges, which can rapidly break down the insulation. The insulation is applied to the coil by winding the mica tape around the coil in several layers. The insulation is impregnated, and then the coil side is painted with a graphite-based paint to improve the contact with the surrounding stator which is connected to earth potential.

The conductor area of the windings is determined by the current intensity in question and by the cooling method used. The conductor and the coil are usually formed with a rectangular shape to maximize the amount of conductor material in the slot. A typical coil is formed of so-called Roebel bars, in which certain of the bars may be made hollow for hosting a coolant therein. A Roebel bar comprises a plurality of rectangular, parallel-connected copper conductors connected in parallel, which are transposed 360 degrees along the slot.

Ringland bars with transpositions of 540 degrees and other transpositions also occur. The transposition is made so as to avoid the occurrence of circulating currents which are generated in a cross section of the conductor material, as viewed from the magnetic field.

For mechanical and electrical reasons, a machine cannot be made in just any size. The machine power is determined substantially by three factors:

- The conductor area of the windings. At normal operating temperature, copper, for example, has a maximum value of 3-3.5 A/mm2.

- The maximum flux density (magnetic flux) in the stator and rotor material.

- The maximum electric held strength in the insulating material, the so-called dielectric strength.

Polyphase AC windings are designed either as single-layer or two-layer windings. In the case of single-layer windings, there is only one coil side per slot, and in the case of two-layer windings there are two coil sides per slot. Two-layer windings are usually designed as diamond windings, whereas the single-layer windings which are relevant in this connection may be designed as a diamond winding or as a concentric winding. In the case of a diamond winding, only one coil span (or possibly two coil spans) occurs, whereas flat windings are designed as concentric windings, that is, with a greatly varying coil span. By coil span it is meant the distance in circular measure between two coil sides belonging to the same coil, either in relation to the relevant pole pitch or in the number of intermediate slot pitches. Usually, different variants of chording are used, for example short-pitching pitch, to give the winding the desired properties.

The type of winding substantially describes how the coils in the slots, that is, the coil sides, are connected together outside the stator, that is, at the end windings ends.

Outside the stacked sheets of the stator, the coil is not provided with a painted conductive earth-potential layer. The end winding end is normally provided with an E-field control in the form of so-called corona protection varnish intended to convert a radial field into an axial field, which means that the insulation on the end windings ends occurs at a high potential relative to earth. This sometimes gives rise to corona in the end-winding-end region, which may be destructive. The so called field-controlling points at the end windings ends entail problems for a rotating electric machine.

Normally, all large machines are designed with a two-layer winding and equally large coils. Each coil is placed with one side in one of the layers and the other side in the other layer. This means that all the coils cross each other in the end winding end. If more than two layers are used, these crossings render the winding work difficult and deteriorate the end winding end.

It is generally known that the connection of a synchronous machine/generator to a power network must be made via a Æ/YD-connected so-called step-up transformer, since the voltage of the power network normally lies at a higher level than the voltage of the rotating electric machine. Together with the synchronous machine, this transformer thus constitutes integrated parts of a plant. The transformer constitutes an extra cost and also has the disadvantage that the total efficiency of the system is lowered. If it were possible to manufacture machines for considerably higher voltages, the step-up transformer could thus be omitted.

During the last few decades, there have been increasing requirements for rotating electric machines for higher voltages than for what has previously been possible to design. The maximum voltage level which, according to the state of the art, has been possible to achieve for synchronous machines with a good yield in the coil production is around 25-30

kV.

Certain attempts to identify a new approach as regards the design of synchronous machines are described, *inter alia*, in an article entitled "Water-and-oil-cooled Turbogenerator TVM-300" in J. Elektrotechnika, No. 1, 1970, pp. 6-8, in U.S. Patent No. 4,429,244 entitled "Stator of Generator", and in Russian patent document CCCP Patent 955369.

The water-and oil-cooled synchronous machine described in J. Elektrotechnika is intended for voltages up to 20 kV. The article describes a new insulation system consisting of oil/paper insulation, which makes it possible to immerse the stator completely in oil. The oil can then be used as a coolant while at the same time using it as insulation. To prevent oil in the stator from leaking out towards the rotor, a dielectric oil-separating ring is provided at the internal surface of the core. The stator winding is made from conductors with an oval hollow shape provided with oil and paper insulation. The coil sides with their insulation are secured to the slots made with rectangular cross section by means of wedges, as coolant oil is used both in the hollow conductors and in holes in the stator walls. Such cooling systems, however, entail a large number of connections of both oil and electricity at the coil ends. The thick insulation also entails an increased radius of curvature of the conductors, which in turn results in an increased size of the winding overhang.

The above-mentioned US patent relates to the stator part of a synchronous machine which comprises a magnetic core of laminated sheet with trapezoidal slots for the stator winding. The slots are tapered since the need for insulation of the stator winding is less towards the interior of the rotor where that part of the winding which is located nearest the neutral point is located. In addition, the stator part comprises a dielectric oil-separating cylinder nearest the inner surface of the core. This part may increase the magnetization

requirement relative to a machine without this ring. The stator winding is made of oil-immersed cables with the same diameter for each coil layer. The layers are separated from each other by way of spacers in the slots and secured by wedges. What is special for the winding is that it comprises two so-called half-windings connected in series. One of the two half windings is located, centered, inside an insulating sleeve. The conductors of the stator winding are cooled by surrounding oil. Disadvantages with such a large quantity of oil in the system are the risk of leakage and the considerable amount of cleaning work which may result from a fault condition. Those parts of the insulating sleeve which are located outside the slots have a cylindrical part and a conical termination reinforced with current-carrying layers, the purpose of which is to control the electric field strength in the region where the cable enters the end winding.

From CCCP 955369 it is clear, in another attempt to raise the rated voltage of the synchronous machine, that the oil-cooled stator winding comprises a conventional high-voltage cable with the same dimension for all the layers. The cable is placed in stator slots formed as circular, radially located openings corresponding to the cross-section area of the cable and the necessary space for fixing and for coolant. The different radially located layers of the winding are surrounded by and fixed in insulating tubes, insulating spacers fix the tubes in the stator slot. Because of the oil cooling, an internal dielectric ring is also needed here for sealing the oil coolant off against the internal air gap. The disadvantages of oil in the system described above also apply to this design. The design also exhibits a very narrow radial waist between the different stator slots, which implies a large slot leakage flux which significantly influences the magnetization requirement of the machine.

A report from Electric Power Research Institute, EPRI, EL-3391 from 1984 describes a review of machine concepts for achieving a higher voltage of a rotating electric machine

with the purpose of being able to connect a machine to a power network without an intermediate transformer. Such a solution, judging from results of the investigation, provides good efficiency gains and great economic advantages. The main reason for considering it possible in 1984 to start developing generators for direct connection to power networks was that, at the time, a super conducting rotor had been produced. The large magnetization capacity of the super conducting field makes it possible to use an air gap winding with a sufficient insulation thickness to withstand the electrical stresses. By combining the most promising concept, according to the project, of designing a magnetic circuit with a winding, a so-called "monolith cylinder armature", a concept where the winding comprises two cylinders of conductors concentrically enclosed in three cylindrical insulating casings and the whole structure being fixed an iron core without teeth, it was judged that a rotating electric machine for high voltage could be directly connected to a power network. The solution meant that the main insulation had to be made sufficiently thick to cope with network-to-network and network-to-earth potentials. The insulation system which, after a review of all the techniques known at the time, was judged to be necessary to manage an increase to a higher voltage was that which is normally used for power transformers and which consists of dielectric-fluid-impregnated cellulose press board. Clear disadvantages with to the proposed solution are that, in addition to requiring a super conducting rotor, it requires a very thick insulation which increases the size of the machine. The end windings ends must be insulated and cooled with oil or freons to control the large electric fields in the ends. The whole machine must be hermetically enclosed to prevent the liquid dielectric from absorbing moisture from the atmosphere.

When manufacturing rotating electric machines according to the state of the art, the winding is manufactured with conductors and insulation systems in several steps, whereby

the winding must be preformed prior to mounting on the magnetic circuit. Impregnation for preparing the insulation system is performed after mounting of the winding on the magnetic circuit.

SUMMARY OF THE INVENTION

It is an object of the invention is to be able to manufacture a rotating electric machine for high voltage without any complicated preforming of the winding and without having to impregnate the insulation system after mounting of the winding.

To increase the power of a rotating electrical machine, it is known to increase the current in the AC coils. This has been achieved by optimizing the quantity of conducting material, that is, by close-packing of rectangular conductors in the rectangular rotor slots. The aim was to handle the increase in temperature resulting from this by increasing the quantity of insulating material and using more temperature-resistant and hence more expensive insulating materials. The high temperature and field load on the insulation has also caused problems with the life of the insulation. In the relatively thick-walled insulating layers which are used for high-voltage equipment, for example impregnated layers of mica tape, partial discharges, PD, constitute a serious problem. When manufacturing these insulating layers, cavities, pores, and the like, will easily arise, in which internal corona discharges arise when the insulation is subjected to high electric held strengths. These corona discharges gradually degrade the material and may lead to electric breakdown through the insulation.

The present invention is based on the realization that, to be able to increase in the power of a rotating electrical machine in a technically and economically justifiable way, this must be achieved by ensuring that the insulation is not broken down by the phenomena

described above. This can be achieved according to the invention by using as insulation layers made in such a way that the risk of cavities and pores is minimal, for example extruded layers of a suitable solid insulating material, such as thermoplastic resins, cross linked thermoplastic resins, rubber such as silicone rubber, etc. In addition, it is important that the insulating layer has an inner layer, surrounding the conductor, with semiconducting properties and that the insulation is also provided with at least one additional outer layer, surrounding the insulation, with semiconducting properties. By semiconducting properties is meant in this context a material which has a considerably lower conductivity than an electric conductor but which does not have such a low conductivity that it is an insulator. By using only insulating layers which may be manufactured with a minimum of defects and, in addition, providing the insulation with an inner and an outer conductive layer, it can be ensured that the thermal and electric loads are reduced. The insulating part with at least one adjoining conductive layer should have essentially the same coefficient of thermal expansion. At temperature gradients, defects caused by different temperature expansion in the insulation and the surrounding layers should not arise. The electric load on the material decreases as a consequence of the fact that the conductive (actually semiconductive) layers around the insulation will constitute equipotential surfaces and that the electrical field in the insulating part will be distributed relatively evenly over the thickness of the insulation. The outer conductive layer may be connected to a chosen potential, for example earth potential. This means that, for such a cable, the outer casing of the winding in its entire length may be kept at, for example, earth potential. The outer layer may also be cut off at suitable locations along the length of the conductor and each cut-off partial length may be directly connected to a chosen potential. Around the outer conductive layer there may also be arranged other layers, casings and the like, such as a metal shield and a protective sheath.

Further knowledge gained in connection with the present invention is that increased current load leads to problems with electric (E) field concentrations at the corners at a cross section of a coil and that this entails large local loads on the insulation there. Likewise, the magnetic (B) field in the teeth of the stator will be concentrated at the corners. This means that magnetic saturation arises locally and that the magnetic core is not utilized in full and that the wave form of the generated voltage/current will be distorted. In addition, eddy-current losses caused by induced eddy currents in the conductors, which arise because of the geometry of the conductors in relation to the B field, will entail additional disadvantages in increasing current densities. Further improvement of the invention is achieved by making the coils and the slots in which the coils are placed essentially circular instead of rectangular. By making the cross section of the coils circular, these will be surrounded by a constant B field without concentrations where magnetic saturation may arise. Also the E field in the coil will be distributed evenly over the cross section and local loads on the insulation are considerably reduced. In addition, it is easier to place circular coils in slots in such a way that the number of coil sides per coil group may increase and an increase of the voltage may take place without the current in the conductors having to be increased. The reason for this being that the cooling of the conductors is facilitated by, on the one hand, a lower current density and hence lower temperature gradients across the insulation and, on the other hand, by the circular shape of the slots which entails a more uniform temperature distribution over a cross section. Additional improvements may also be achieved by composing the conductor from smaller parts, so-called strands. The strands may be insulated from each other and only a small number of strands may be left uninsulated and in contact with the inner conductive layer, to ensure that the inner conductive layer of the insulator is at the same potential as the conductor.

The advantages of using a rotating electric machine according to the invention include that the machine can be operated at overload for a considerably longer period of time than what is usual for such machines without being damaged. This is a consequence of the composition of the machine and the limited thermal load of the insulation. It is, for example, possible to load the machine with up to 100% overload for a period exceeding 15 minutes and up to two hours.

One embodiment according to the invention is that the magnetic circuit of the rotating electric machine includes a winding of a threaded cable with one or more extruded insulated conductors with solid insulation with a conductive layer both at the conductor and the casing. The outer conductive layer may be connected to earth potential. To be able to cope with the problems which arise in case of direct connection of rotating electric machines to all types of high-voltage power networks, a machine according to the invention has a number of features which distinguish it from the state of the art.

As described above, a winding for a rotating electric machine may be manufactured from a cable with one or more extruded insulated conductors with solid insulation with a conductive layer (which may include a semiconductive layer) both at the conductor and at the casing.

Some typical examples of insulating materials are thermoplastics like LDPE (low density polyethylene), HDPE (high density polyethylene), PP (polypropylene), PB (polybutylene), PMP (polymethylpentene) or cross-linked materials like XLPE (cross linked polyethylene) or rubber insulation like EPR (ethylene propylene rubber) or silicone rubber.

A further development of a conductor composed of strands is possible in that it is possible to insulate the strands with respect to each other in order to reduce the amount of eddy current losses in the conductor. One or a few strands may be left uninsulated to ensure

that the conductive layer which surrounds the conductor is at the same potential as the conductor.

It is known that a high-voltage cable for transmission of electric energy is composed of conductors with solid extruded insulation with an inner and an outer conductive part. In the process of transmitting electric energy it was required that the insulation should be free from defects. During transmission of electric energy, the starting-point has long been that the insulation should be free from defects. When using high-voltage cables for transmission of electric energy, the aim was not to maximize the current through the cable since space is no limitation for a transmission cable.

Insulation of a conductor for a rotating electric machine may be applied in some other way than by way of extrusion, for example by spraying or the like. It is important, however, that the insulation should have no defects through the whole cross section and should possess similar thermal properties. The conductive layers may be supplied with the insulation in connection with the insulation being applied to the conductors.

Preferably, cables with a circular cross section are used. Among other things, to obtain a better packing density, cables with a different cross section may be used.

To build up a voltage in the rotating electric machine, the cable is arranged in several consecutive turns in slots in the magnetic core. The winding can be designed as a multi-layer concentric cable winding to reduce the number of end winding-end crossings. The cable may be made with tapered insulation to utilize the magnetic core in a better way, in which case the shape of the slots may be adapted to the tapered insulation of the winding.

A significant advantage of a rotating electrical machine according to the invention is that the E field is near zero in the end-winding-end region outside the outer conductive layer and that with the outer casing at earth potential, the electric field need not be controlled. This

means that no field concentrations can be obtained, neither within sheets, in end-winding-end regions or in the transition therebetween.

The present invention also relates to a method for manufacturing the magnetic circuit and, in particular, the winding. The method for manufacturing includes placing the winding in the slots by threading a cable into the openings in the slots in the magnetic core. Since the cable is flexible, it can be bent and this permits a cable length to be located in several turns in a coil. The end windings ends will then have bending zones in the cables. The cable may also be joined in such a way that its properties remain constant over the cable length. This method entails considerable simplifications compared with the state of the art. The so-called Roebel bars are not flexible but must be preformed into the desired shape. Impregnation of the coils is also an exceedingly complicated and expensive technique when manufacturing rotating electric machines today.

This is achieved with an insulated conductor for high-voltage windings in rotating electric machines as described herein. The high-voltage cable according to the present invention includes one or more strands surrounded by a first conductive layer. This first conductive layer is in turn surrounded by a first insulating layer which is surrounded by a second conductive layer. This second conductive layer is connected to ground potential at least two different points along the high-voltage cable, i.e., at the inlet and outlet of the stator. The second conductive layer has a resistivity which on the one hand minimizes the electric losses in the second conductive layer, and on the other hand contributes to the voltage induced in the second conductive layer minimizing the risk of glow discharges.

By way of the high-voltage cable according to the invention, described above, a high-voltage cable is obtained in which electric losses caused by induced voltages in the outer conductive layer can be avoided. A high-voltage cable is also obtained in which the risk of

electrical discharges is minimized. Furthermore, this is obtained with a cable which is simple to manufacture.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be explained in more detail in the following description of preferred embodiments, with reference to the accompanying drawings in which:

Figure 1 shows a cross section of a high-voltage cable according to the present invention;

Figure 2 shows a basic diagram explaining what affects the voltage between the conductive surface and earth; and

Figures 3 is a graph illustrating the potential on the conductive surface in relation to the distance between grounded points.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the drawings wherein like reference numerals designate identical or corresponding parts throughout the several views, and more particularly to Figure 1, Figure 1 shows a cross-sectional view of a high-voltage cable 10 according to the present invention. The high-voltage cable 10 shown includes an electric conductor which may have one or more strands 12 of copper (Cu), for instance, having circular cross section. These strands 12 are arranged in the middle of the high-voltage cable 10. Around the strands 12 is a first conductive layer 14, and around the first conductive layer 14 is a first insulating layer 16, e.g., XLPE insulation. Around the first insulating layer 16 is a second conductive layer 18.

Figure 2 shows a basic diagram explaining what affects the voltage between the second conductive surface and earth. The resultant voltage, U_s, between the surface of the

second conductive layer 18 and earth may be expressed as follows:

$$U_s = \sqrt{U^2_{max} + U^2_{ind}} \tag{1}$$

where U_{max} is the result of capacitive current in the surface and where U_{ind} is voltage induced from magnetic flux. To avoid surface discharges U_s must be <250 V, preferably U_s <130 through 150 V.

In principle U_{ind} creates no problems assuming grounding at both stator ends. Thus $U_s \approx U_{max}$ where the maximum value U_{max} at the middle of the conductor is given by

$$U_{max} \approx (2\pi f C_l U_f)^2 \frac{\rho_s l^2}{A_s}$$

where f = frequency; C_l = transverse capacitance per length unit; U_f = phase-to ground voltage; ρ_s = the resistivity of the conductive layer 18; A_s = the cross sectional area of the conductive layer 18, and l = the length of the stator.

One way of preventing losses caused by induced voltages in the second conductive layer 18 is to increase its resistance. Since the thickness of the layer cannot be reduced for technical reasons relating to manufacture of the cable and stator, the resistance can be increased by selecting a coating or a compound that has higher resistivity.

If the resistivity is increased too much the voltage on the second conductive layer mid-way between the grounded points (that is, inside the stator) will be so high that there will be risk of glow discharge and consequently erosion of the conductive material and the insulation.

The resistivity ρ_s of the second conductive layer 18 should therefore lie within an interval:

$$\rho_{min} < \rho_s < \rho_{max} \tag{2}$$

where ρ_{min} is determined by permissible power loss caused by eddy current losses and resistive losses caused by U_{ind} . ρ_{max} is determined by the requirement for no glow discharge.

Experiments have shown that the resistivity ρ_s of the second conductive layer 18 should be between 10-500 ohm*cm. To obtain good results with machines of all sizes ρ_s should be between 50-100 ohm*cm.

Figure 3 shows a diagram illustrating potentials on the conductive surface in relation to the distance between earthing points.

An example of a suitable conductive layer 18 is one manufactured of EPDM material mixed with carbon black. The resistivity can be determined by varying the type of base polymer and/or varying the type of carbon black and/or the proportion of carbon black.

The following are a number of examples of different resistivity values obtained using various mixtures of base polymer and carbon black.

Base polymer	**Carbon black type**	**Carbon black quantity %**	**Volume resistivity ohm*cm**
Ethylene vinyl acetate copolymer/nitrile rubber	EC carbon black	approx. 15	350-400
""	P-carbon black	approx. 37	70-10
""	Extra conducting carbon black, type I	approx. 35	40-50
""	Extra conducting carbon black, type II	approx. 33	30-60
Butyl grafted polythene	""	approx. 25	7-10
Ethylene butyl acrylate copolymer	Acetylene carbon black	approx. 35	40-50
""	P carbon black	approx. 38	5-10
Ethylene propene rubber	Extra conducting carbon black	approx. 35	200-400

The invention is not limited to the embodiments shown. Several variations are feasible within the scope of the appended claims.

CLAIMS

1. An insulated conductor (10) for high-voltage windings in electric machines, characterized in that the insulated conductor (10) comprises one or more strands (12), an inner, first conductive layer (14) surrounding the strands (12), a first insulating layer (16) surrounding the inner, first conductive layer (14) and an outer, second conductive layer (18) surrounding the first insulating layer (16), and the resistivity of the second conductive layer (18) is between 10-500 ohm*cm.

2. An insulated conductor (10) as claimed in claim 1, characterized in that the conductive layer (18) is earthed at at least two different points along the insulated conductor (10).

3. An insulated conductor (10) as claimed in claim 2, characterized in that the resistivity of the second conductive layer (18) is lower than that of the insulation layer (16) but higher than that of the material of the strands (12).

4. An insulated conductor (10) as claimed in claim 3, characterized in that the resistivity of the second conductive layer (18) is between 50-100 ohm*cm.

5. An insulated conductor (10) as claimed in claim 1, characterized in that the resistance per axial length unit of the second conductive layer (18) is between 5-50000 ohm/m.

6. An insulated conductor (10) as claimed in claim 1, characterized in that the resistance per axial length unit of the second conductive layer (18) is between 500-25000 ohm/m.

7. An insulated conductor (10) as claimed in claim 1, characterized in that the resistance per axial length unit of the second conductive layer (18) is between 2500-5000 ohm/m.

8. An insulated conductor (10) as claimed in any of the preceding claims, characterized in that the resistivity of the second conductive layer (18) is determined by varying the type of base polymer and varying the type of carbon black and the proportion of carbon black.

9. An insulated conductor (10) as claimed in claim 7, characterized in that the base polymer is chosen from ethylene butyl acrylatecopolymers of EP-rubber.

10. An insulated conductor (10) as claimed in claims 7-8, characterized in that the second conductive layer (18) is cross-linked by peroxide.

11. An insulated conductor (10) as claimed in any of the preceding claims, characterized in that the adhesion between the insulation layer (16) and the second conductive layer (18) is of the same order of magnitude as the intrinsic strength of the insulation material.

12. An insulated conductor (10) as claimed in any of the preceding claims, characterized in that the first conductive layer (14), the insulating layer (16) and the second conductive layer (18) are extruded on the conductive strands (12).

13. An insulated conductor (10) as claimed in claim 11, characterized in that all layers are applied through extrusion through a multi layer head.

14. An insulated conductor (10) as claimed in any of the preceding claims, characterized in that the insulating layer (16) is a crosslinked polyethylene, XLPE.

15. An insulated conductor (10) as claimed in any of the preceding claims, characterized in that the insulating layer (16) is made of ethylenepropylene rubber or silicone rubber..

16. An insulated conductor (10) as claimed in any of the preceding claims characterized in that the insulating layer (16) is made of a thermoplastic material as LDPE, HDPE, PP, PB, PMP.

17. An electric machine comprising an insulated conductor as claimed in any of claims 1-16.

18. An rotating electrical machine comprising an insulated conductor as claimed in any of claims 1-16.

IN THE ABSTRACT OF THE DISCLOSURE

An insulated conductor for high-voltage windings and electric machine, and rotating electric machine that use the insulated conductor. The insulated conductor is suitable for use in a high-voltage winding application for devices such as an electric machine and a rotating electric machine. A feature of the insulated conductor is that the conductor includes at least one strand, and an inner conductive layer that surrounds the at least one strand. An insulating layer surrounds the inner conductive layer, and an outer conductive layer surrounds the insulating layer. When arranged in this manner, and when the outer conductive layer is suitably configured to provide an equipotential surface, the insulated conductor provides relatively high resistance to breakdown when operating at high voltages.

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Declaration, Power Of Attorney and Petition

WE (I) the undersigned inventor(s), hereby declare(s) that:

My residence, post office address and citizenship are as stated below next to my name,

We (I) believe that we are (I am) the original, first, and joint (sole) inventor(s) of the subject matter which is claimed and for which a patent is sought on the invention entitled

INSULATED CONDUCTOR FOR HIGH-VOLTAGE WINDINGS

the specification of which

☐ is attached hereto.

☒ was filed on ______________________ as

Application Serial No. ______________________

and amended on ______________________ .

☒ was filed as PCT international application

Number PCT/SE97/00903

on 27 May 1997,

and was amended under PCT Article 19

on ______________________ (if applicable).

We (I) hereby state that we (I) have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

We (I) acknowledge the duty to disclose information known to be material to the patentability of this application as defined in Section 1.56 of Title 37 Code of Federal Regulations.

We (I) hereby claim foreign priority benefits under 35 U.S.C. § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed. Prior Foreign Application(s)

Application No.	Country	Day/Month/Year	Priority Claimed	
9602079-7	SWEDEN	29 May 1996	☒ Yes	☐ No
9602091-2	SWEDEN	29 May 1996	☒ Yes	☐ No
			☐ Yes	☐ No
			☐ Yes	☐ No

We (I) hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

(Application Number) (Filing Date)

(Application Number) (Filing Date)

We (I) hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s), or § 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

Application Serial No.	Filing Date	Status (pending, patented, abandoned)
PCT/SE97/00903	27 May 1997	

And we (I) hereby appoint: Norman F. Oblon, Registration Number ~~24,618; Marvin J. Spivak, Registration Number 24,913;~~ C. Irvin McClelland, Registration Number ~~21,124; Gregory J. Maier, Registration Number 25,599;~~ Arthur I. Neustadt, Registration Number 24,854; Richard D. Kelly, Registration Number ~~27,757; James D. Hamilton, Registration Number 28,421;~~ Eckhard H. Kuesters, Registration Number 28,870; Robert T. Pous, Registration Number ~~29,099; Charles L. Gholz, Registration Number 26,395; Vincent J. Sunderdick, Registration Number 29,004;~~ William E. Beaumont, Registration Number ~~30,996; Steven B. Kelber, Registration Number 30,073;~~ Robert F. Gnuse, Registration Number 27,295; Jean-Paul Lavalleye, Registration Number 31,451; Stephen G. Baxter, Registration Number 32,884; Martin M. Zoltick, Registration Number ~~35,745;~~ Robert W. Hahl, Registration Number ~~33,893; Richard L. Treanor, Registration Number 36,379;~~ Steven P. Weihrouch, Registration Number ~~32,829; John T. Goolkasian, Registration Number 26,142;~~ Marc R. Labgold, Registration Number ~~34,651; William J. Healey, Registration Number 36,160;~~ Richard L. Chinn, Registration Number 34,305; Steven E. Lipman, Registration Number ~~30,011; Carl E. Schlier, Registration Number 34,426; James J. Kulbaski, Registration Number 34,648; Catherine B. Richardson, Registration Number 39,007;~~ Richard A. Neifeld, Registration Number 35,299; J. Derek Mason, Registration Number ~~35,270; and Surinder Sachar 34,423;~~ our (my) attorneys, with full powers of substitution and revocation, to prosecute this application and to transact all business in the Patent Office connected therewith; and we (I) hereby request that all correspondence regarding this application be sent to the firm of ~~OBLON, SPIVAK, McCLELLAND, MAIER & NEUSTADT, P.C., whose~~ Post Office Address is: ~~Fourth Floor, 1755 Jefferson Davis Highway, Arlington, Virginia 22202.~~

We (I) declare that all statements made herein of our (my) own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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